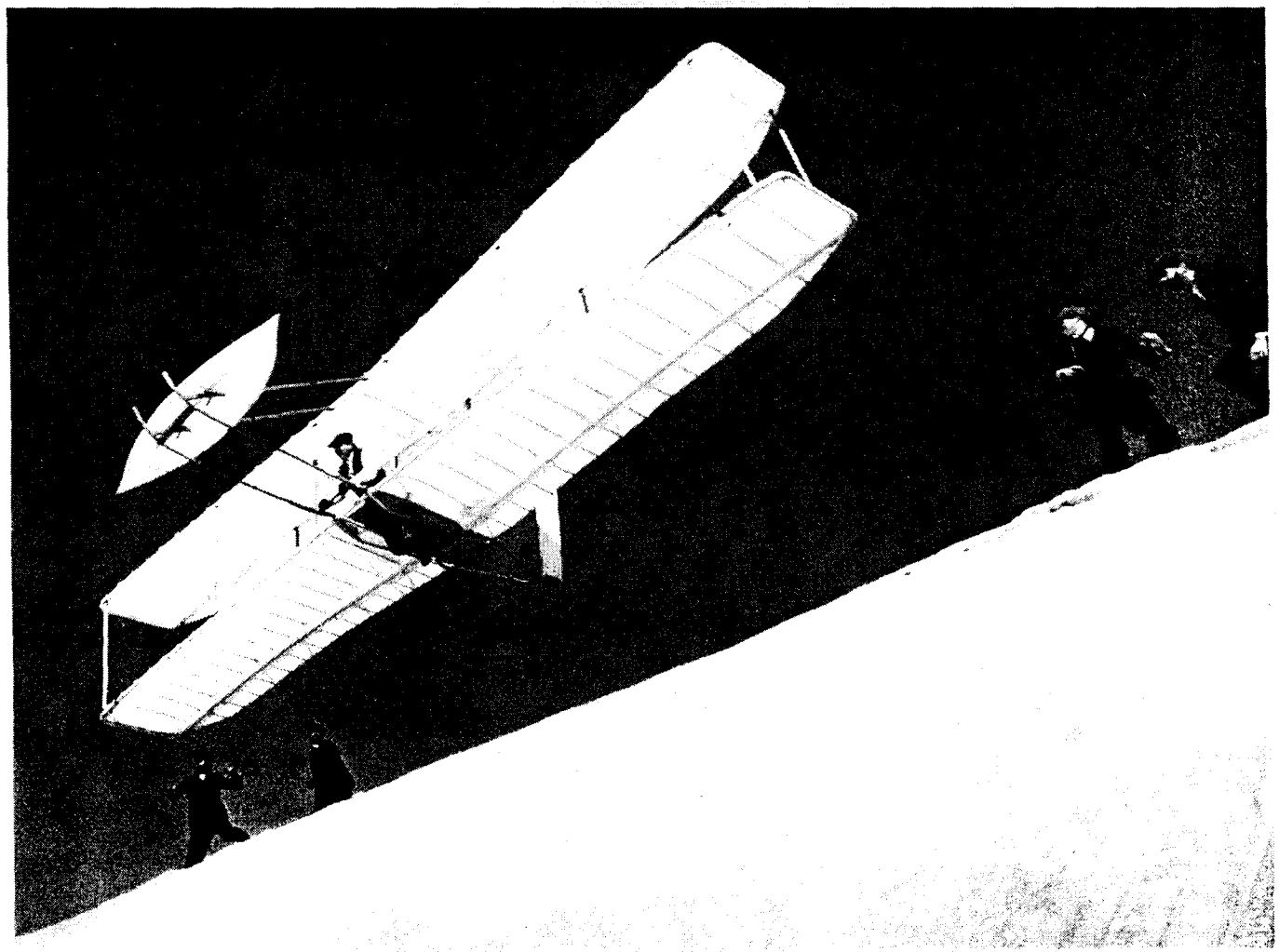
THE WRIGHT BROTHER'S HISTORICAL EVENT OF 1903



A replica of the Wright Brothers' 1903 glider soars over the dunes of Kitty Hawk, North Carolina.

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Kitty Hawk Demonstration of Bioinspired Engineering of Exploration Systems (BEES)

Steven Zornetzer*,
Sarita Thakoor, Chuck Jorgensen*, and Butler Hine***

NASA, AMES Research Center*
Jet Propulsion Laboratory**

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Presentation DARPA CBBS PI Meeting, March 18-21, 2001 held at Breckenridge Colorado

KITTY HAWK DEMO OF BIOINSPIRED ENGINEERING OF EXPLORATION SYSTEMS (BEES)

- THE PROLOGUE: BEES 1998 & BEES 2000
- KITTY HAWK ANNIVERSARY PACE-SETTING DEMO
  - ILLUSTRATION
  - OBJECTIVES- MISSION GOAL
  - TECHNOLOGY DEMO ELEMENTS
- NEXT STEPS:
- KHD BEES: MISSION PAYOFF
- MARS EXPLORATION PLAN
- BIO-INSPIRED TECHNOLOGY - MARS EXPLORATION
- APPLICATIONS & PAYOFF

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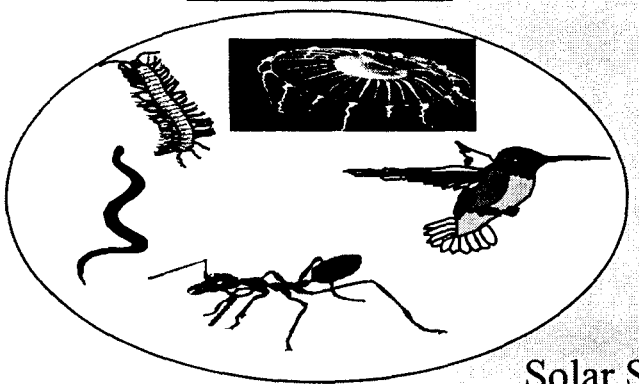
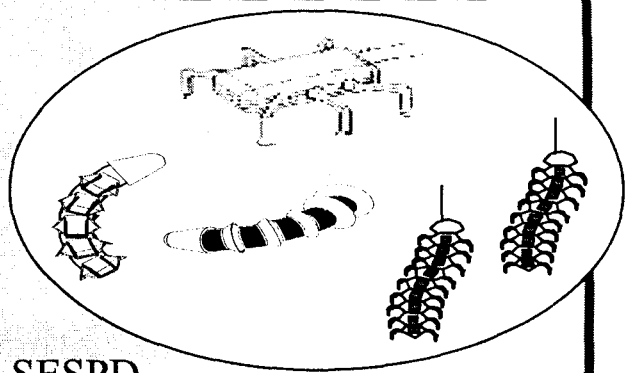
BIOINSPIRED ENGINEERING OF EXPLORATION SYSTEMS

1st NASA/JPL Workshop on Biomorphic Explorers for Future Missions

INSPIRATION

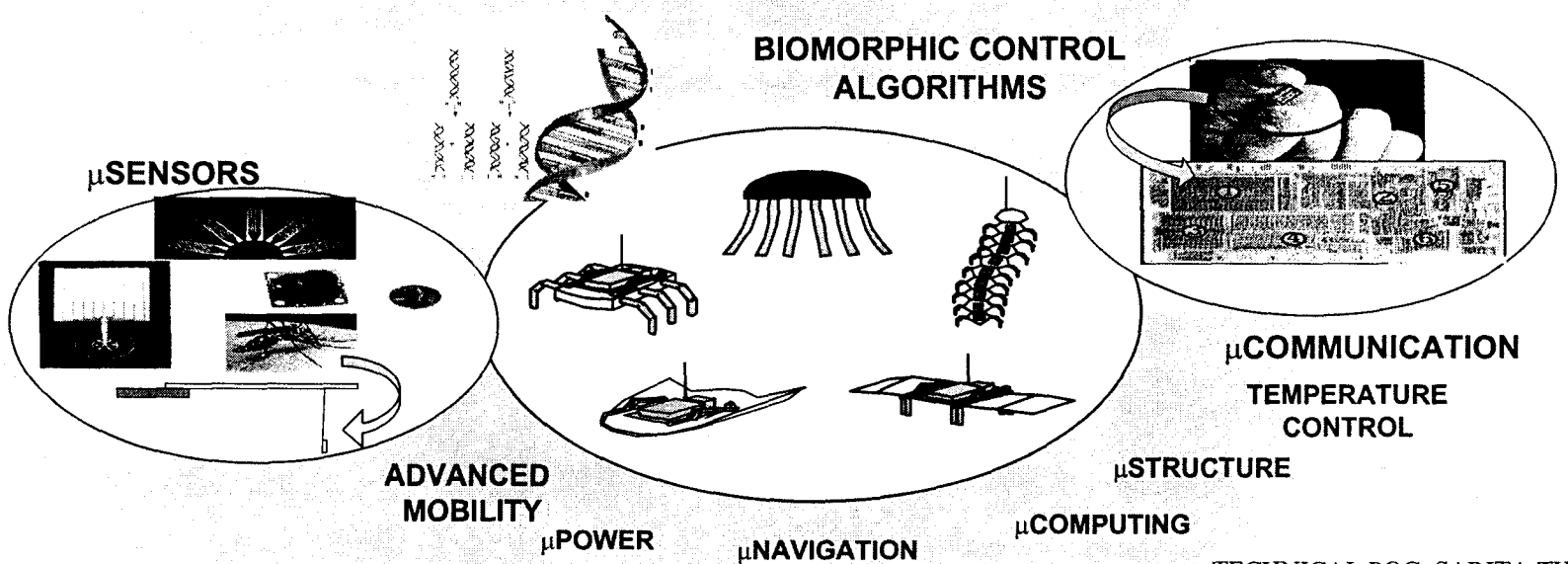


IMPLEMENTATION



August 19 - 20, 1998
Jet Propulsion Laboratory
Pasadena, CA
Auditorium 180 - 101

Sponsored by NASA/JPL
Solar System Exploration Program, SESPD
New Millennium Program, NMP
Space Mission Technology Development Program, TAP
Center for Integrated Space Microsystems, CISM



TECHNICAL POC: SARITA THAKOOR
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BIOINSPIRED ENGINEERING OF EXPLORATION SYSTEMS

NASA/DoD SECOND BIOMORPHIC EXPLORERS

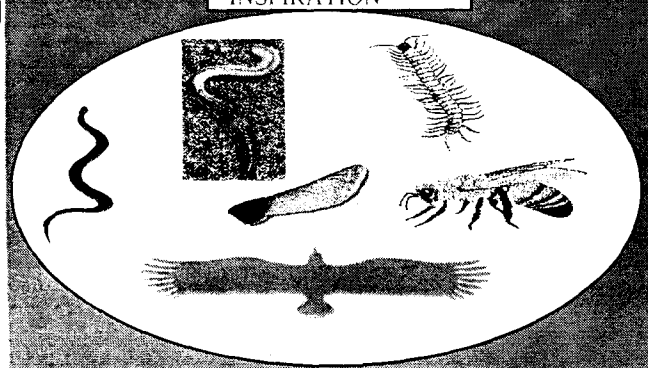
BIOINSPIRED ENGINEERING OF EXPLORATION SYSTEMS 2000

December 4 - 6, 2000

Jet Propulsion Laboratory

Pasadena, CA

INSPIRATION



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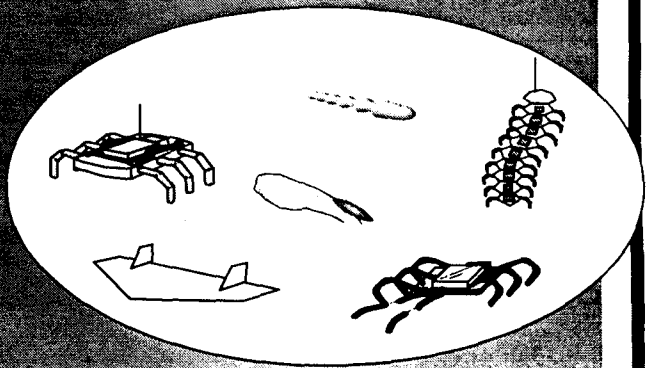
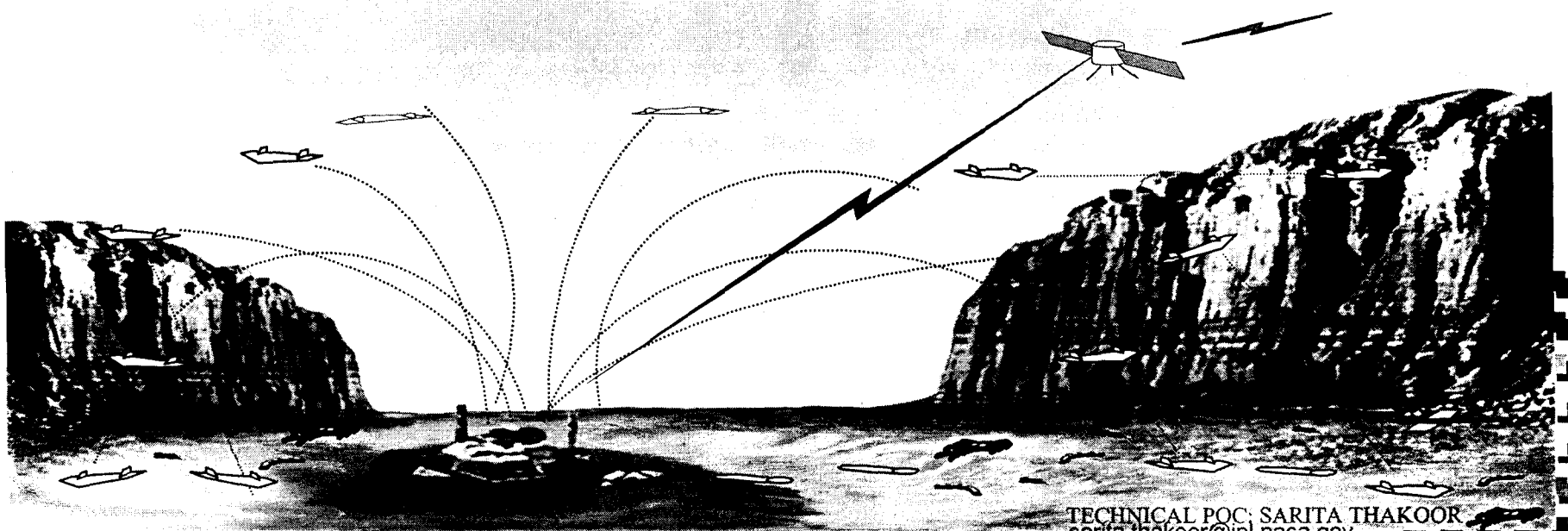


WORKSHOP PROGRAM AND ABSTRACTS

Sponsored by NASA



TECHNICAL POC: SARITA THAKOOR
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Summary of NASA/DoD BEES 2000 Workshop

- Attracted excellent participants from multiple NASA centers, academia, the medical community and industry.
- Day 1 - Biomorphic Surface Systems and Enabling Technologies for Biomorphic Missions.
- Day 2 - Vision & Motivation for BEES, Biomorphic Flight Systems and Bio-Inspired Navigation.
- Day 3 - Sensory info processing and multi-sensor fusion, concluding with panel discussion.
- Conclusion: general consensus to organize a joint NASA-DoD-Industry project to demonstrate BEES technologies.

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KITTY HAWK DEMONSTRATION (KHD) of BEES

- **PURPOSE:**
  - •Celebrate the anniversary of Kitty Hawk, the first successful powered flight by humankind on Dec 17, 1903.
  - •Demonstrate the first fully autonomous (unmanned - no human in the loop) robotic mission.
- **MISSION SCENARIO:**
  - • Mother ship(s) (autonomous helicopter?) flies into the target area
  - • A variety of biologically-inspired microfliers are released each containing biologically inspired technologies capable of, for example, autonomous real time navigation, visual search, plume detection (e.g. following water vapor), intelligent flight control, sensory data fusion, etc.
- **SUCCESS DEFINED BY:** Demonstration of biologically inspired autonomous adaptive flight control utilizing onboard biologically inspired landmark/feature recognition, navigation and visual guidance systems at a selected location on earth in a MARS analog terrain emulating selected conditions on Mars. A set of pre-selected scientific tests will be performed.

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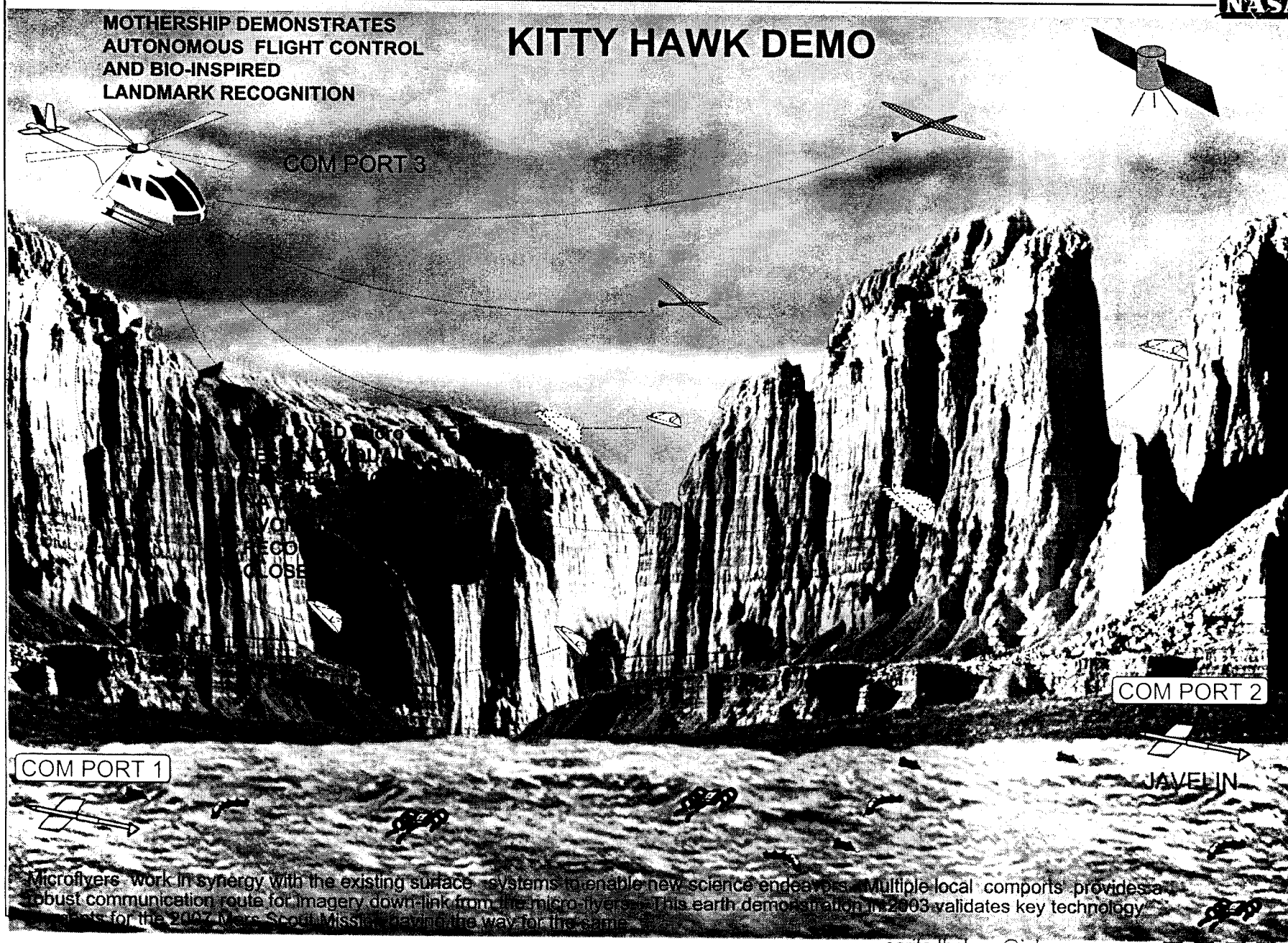
BIOINSPIRED ENGINEERING OF EXPLORATION SYSTEMS



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KHD CORE ACTIVITY

- DEPLOYING MOTHERSHIP(S):
  Candidates : Helicopter, fixed wing, DoD/Industry Deployment
  - •PAYLOAD ~ 25-30 Kg

- BIO-INSPIRED TECHNOLOGY DEMO PAYLOAD CANDIDATES:
  - •NN BASED INTELLIGENT FLIGHT CONTROL
  - •NN BASED FEATURE RECOGNITION & IMAGING
  - •BIO- INSPIRED NAVIGATION
    - •OBSTACLE AVOIDANCE
    - •TERRAIN FOLLOWING
    - •PAYLOAD DEPLOYMENT & CLOSE-UP IMAGING

- BIO-INSPIRED SEARCH/HOMING STRATEGIES
  - •
  - •
  - •

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---- NEXT STEPS ----

- BIO-INSPIRED TECHNOLOGY : 2 PAGE WHITE PAPER 4/15

- EVALUATION CRITERIA:
  - LEVEL OF BIO-INSPIRATION –DESIGN/PAYLOAD
  - RELEVANCE TO MARS MISSION
  - TECHNOLOGY READINESS
  - EASE OF DEPLOYABILITY/SYSTEM INTEGRATION
  - COST

- PROJECT PRESENTATION TO NASA HQ (APRIL/MAY 2001)

- SELECTION PROCESS
- COMPETITION GUIDELINE

- IMPLEMENT KITTY HAWK DEMO (July 2001 - DEC 2003)

- INSERT KHD TECHNOLOGY INTO MARS 2007 MISSION (2003 - 2007)

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HOW KITTY HAWK TECHNOLOGY DEMO OF 2003
WILL PAVE THE WAY FOR
FUTURE BIOMORPHIC MISSIONS ON
MARS ?

---- MISSION PAYOFF ----

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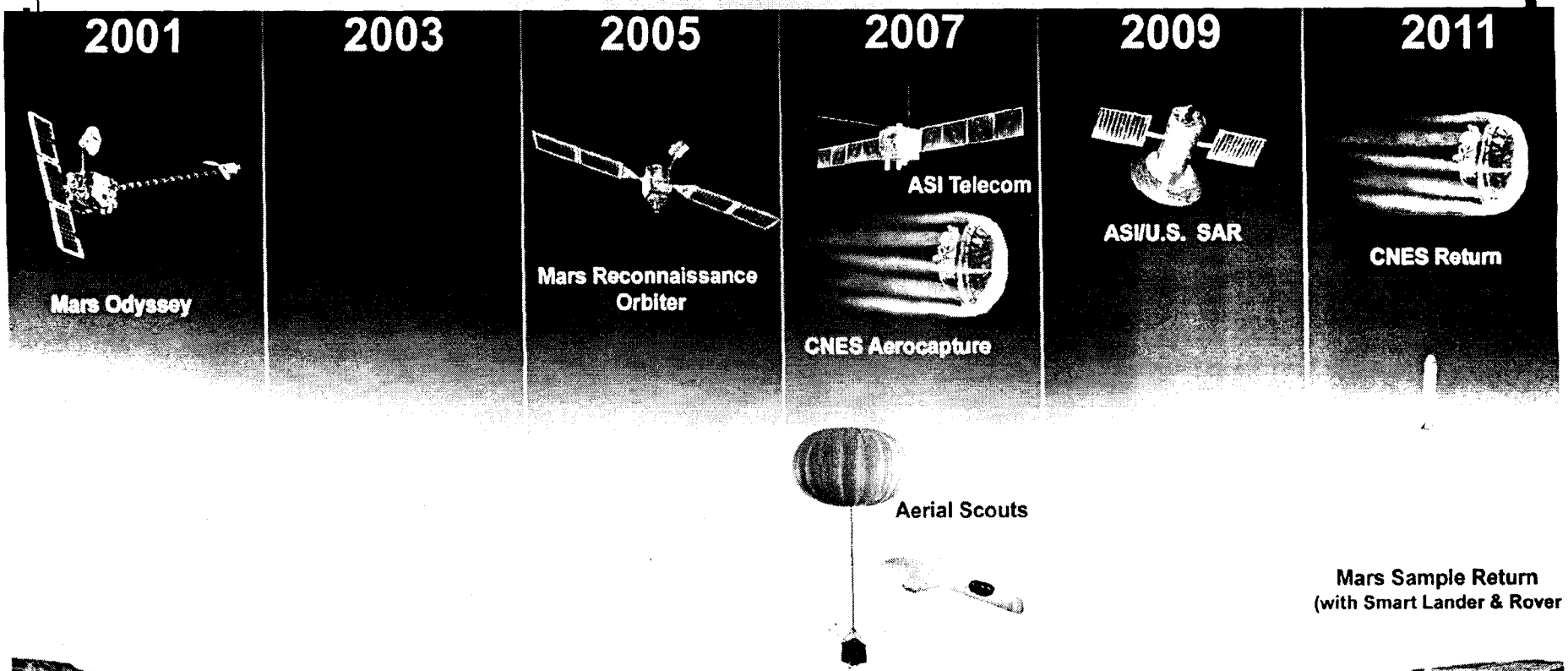
MARS EXPLORATION: THE PLAN



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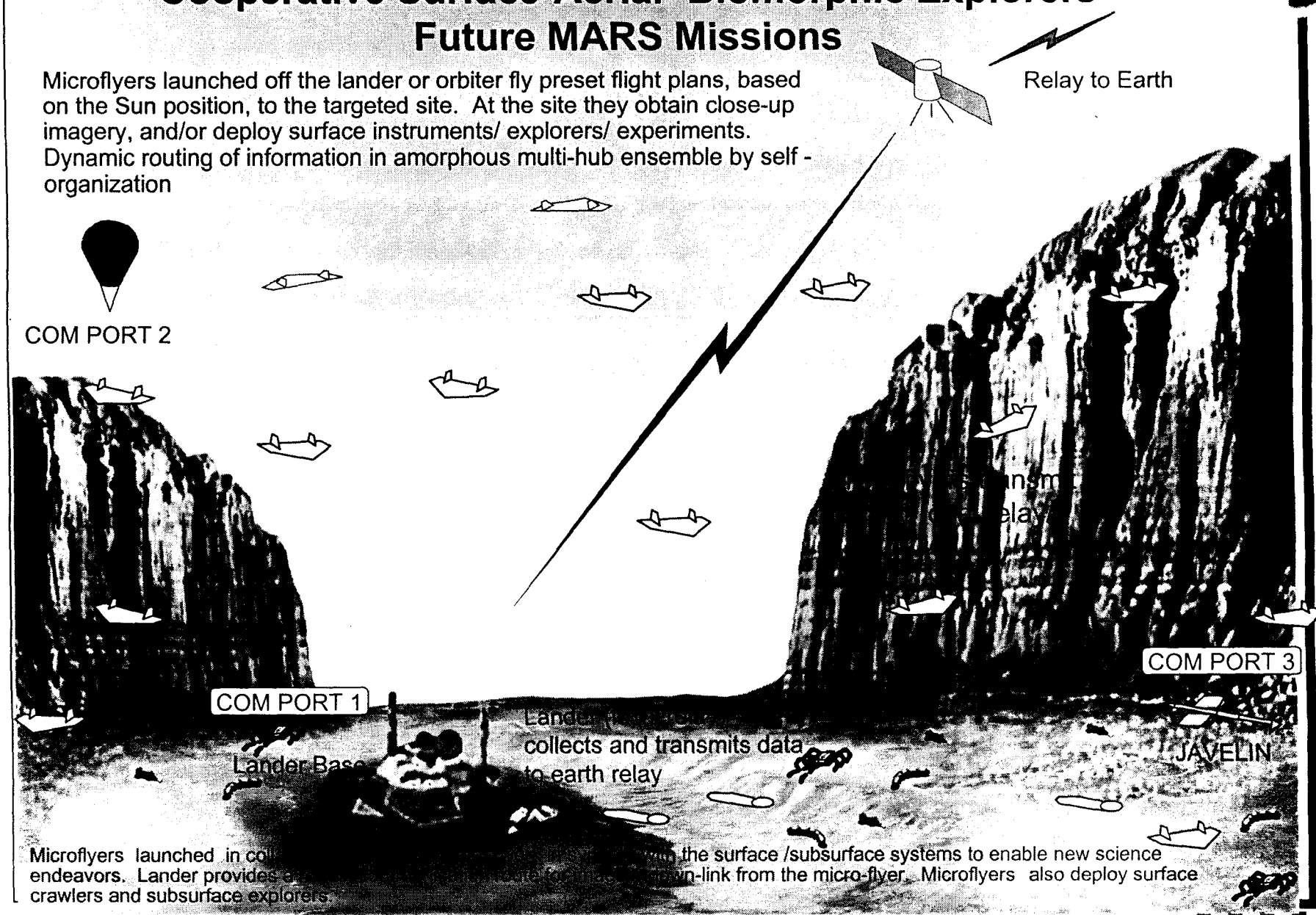
Cooperative Surface-Aerial- Biomorphic Explorers
Future MARS Missions

Microflyers launched off the lander or orbiter fly preset flight plans, based on the Sun position, to the targeted site. At the site they obtain close-up imagery, and/or deploy surface instruments/ explorers/ experiments. Dynamic routing of information in amorphous multi-hub ensemble by self - organization



Microflyers launched in co… …with the surface /subsurface systems to enable new science endeavors. Lander provides e… …n-link from the micro-flyer. Microflyers also deploy surface crawlers and subsurface explorers.

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Science Applications

... WHICH WOULD BE ENABLED/ENHANCED BY SUCH EXPLORERS.....

- VALLES MARINERIS EXPLORATION
  - ONE SINGLE SITE RICH IN GEOLOGIC UNITS
  - STUDY STRATIGRAPHIC COLUMN TOP TO BOTTOM ALONG THE CANYON WALL
  - OPTIMUM SCIENCE SAMPLE SITE

  ... imager, temperature sensor, pressure sensor, sniffer: e-nose, individual gases, elements, etc.

- SCOUTING FOR CONDITIONS COMPATIBLE WITH LIFE TO LEAD US TO THE SPOTS THAT MAY HOLD SAMPLES OF EXTINCT/EXTANT LIFE
  - WIDE-AREA SEARCH WITH INEXPENSIVE EXPLORERS EXECUTING DEDICATED SENSING FUNCTIONS: close-up imaging!!!!

  ... Individual gases, sniffer: e-nose, chemical reactions, pyrotechnic test, elements, specific amino acids, signatures of prebiotic chemistry, etc.

- GEOLOGICAL DATA GATHERING:
  - DISTRIBUTED TEMPERATURE SENSING
  - SEISMIC ACTIVITY MONITORING
  - VOLCANIC SITE

  ... Multitude of explorers working in a cascade or daisy-chain fashion cooperatively to fulfill task

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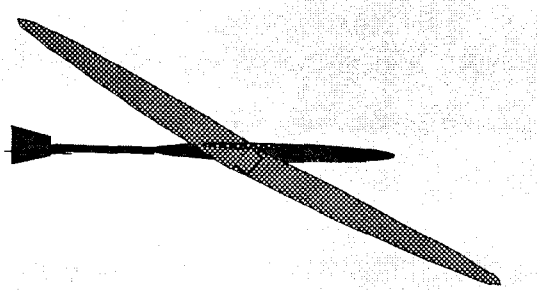
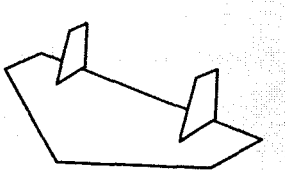
Biomorphic Microflyers

- WHY MICROFLYERS? HUGE RANGE, AERIAL COVERAGE FOR LOW MASS(~ 1 Kg)
- BIOINSPIRED:FORM, FUNCTION, BEHAVIOR

...INSECT FLYERS





INNATE ABILITIES:
- NAVIGATION
- SOARING
- COOPERATIVE STRATEGIES

COGNITIVE ABILITIES
- PATTERN RECOGNITION
- ADAPTIVE CONTROL, RECONFIGURABILITY
- FAULT TOLERANCE

•Aerial launch: can use potential energy of deploying craft

• Surface Launch options: spring, compressed gas launch, rocket boosted, electric etc

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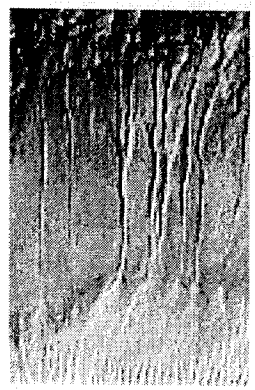
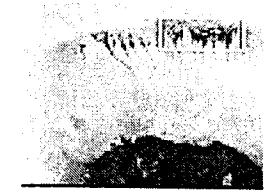
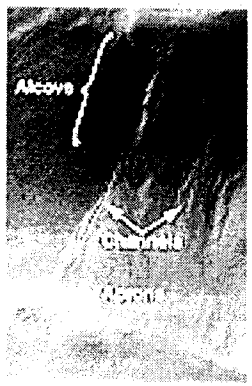
FEATURES OF INTEREST




CLASS 1





CLASS 3

CLASS 2

SCIENCE GOAL FOR MARS: "FOLLOW THE WATER" ⇒ LOCATE WATER FLOW FEATURES, NAVIGATE TO THEM , IMAGE THEM CLOSE-UP AND DEPLOY INSTRUMENTS AT SUCH SELECTED SITES FOR DETAILED IN-SITU MEASUREMENTS

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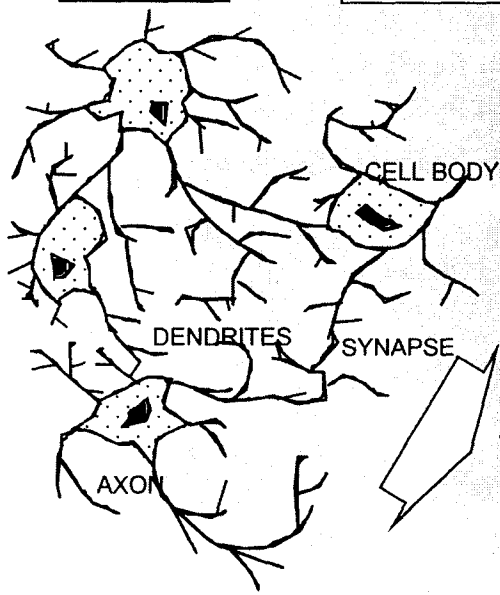
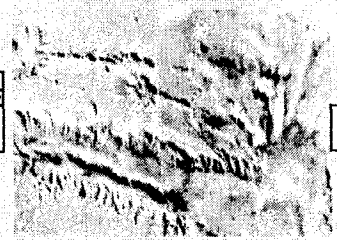
Enabling Processor for Landmark/Feature Recognition

BIOLOGICAL NEURAL NETWORK



WATER-FLOW FEATURE RECOGNITION



TOPOGRAPHY MAP

Input to

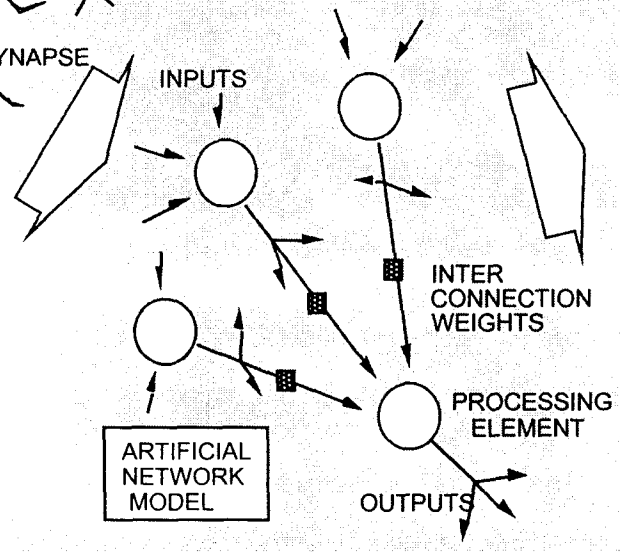
Neural Network Image Classifier (3-layer feed-forward network)

TRAINED WITH WATER-FLOW FEATURE LIBRARY

Neural Network Image Processor

64 Analog Outputs

Identified Feature



Low Power Analog
Massively Parallel
Bio-Inspired Processor

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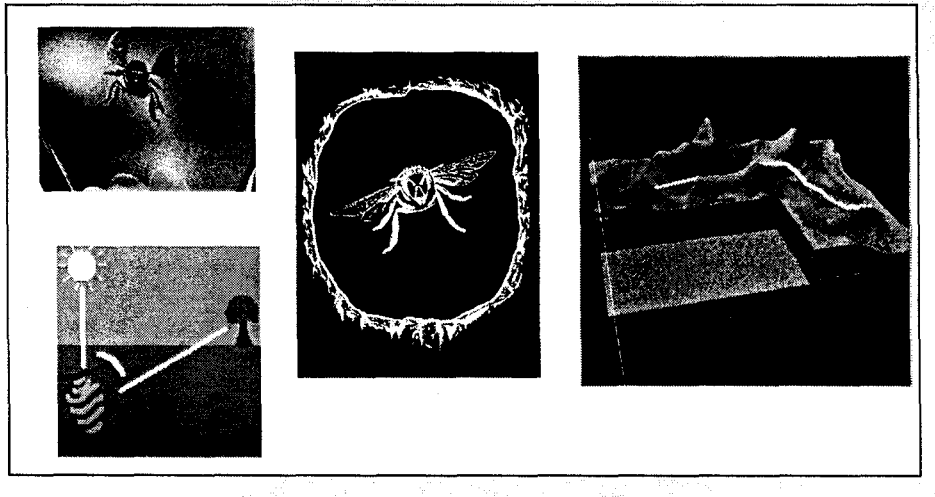
Biomorphic Navigation

Insects (for example honey bees) cope remarkably well with their world, despite possessing a brain that carries fewer than 0.01% as many neurons as ours does. Although most insects have immobile eyes, fixed focus optics(no range info) and lack stereo vision, they use a number of ingenious strategies for perceiving their world in three dimensions and navigating successfully in it. Our intent is to distill some of these 'bee' inspired strategies to obtain unique solutions to navigation and landing and explore the feasibility of incorporating these success strategies in our microflyers for future missions



Karl von Frisch, 1965
Wehner and Rossel, 1985
Barbara Shipman, 1997
Srinivasan et al, 2000, 1997

Honeybee Inspired landing, terrain following, gorge following, obstacle avoidance and point-to-point navigation

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Neurally Inspired Intelligent Flight Control

The neurally inspired intelligent flight control experiment would demonstrate a real time capability to respond to changes in aircraft stability due to varying weather conditions and make adjustments to maintain the best possible flight performance. Successful imaging of selected identified landmarks needs good aircraft attitude stability so these individual technology elements are very synergistic in requirements towards the KHD mission goal. Further in the future, such adaptive controls, providing for on-the-fly reconfigurability and self healing capability in flight are valuable to obtain and enable biomorphic missions

Imagery and Other Desired Instrument Suite

- In-flight imaging of the selected sites and features using
  - Pan-Cam Video, Context Camera
  - High Resolution Cameras (visible, IR and thermal IR)
  - High Resolution Spectrometer
- Deploy at site, miniature In-situ Camera and/or miniature spectrometer
- In - flight (en-route) atmospheric measurements can easily be performed
- Surface measurements:
  - Microphone to hear surface sounds, wind and particle impact noises
  - Electrical Measurement of surface conductivity
  - Accelerometer Measurement of surface hardness
  - Seismic measurement (accelerometers)
  - Water vapor abundance sensing (hydrothermal vent detection)

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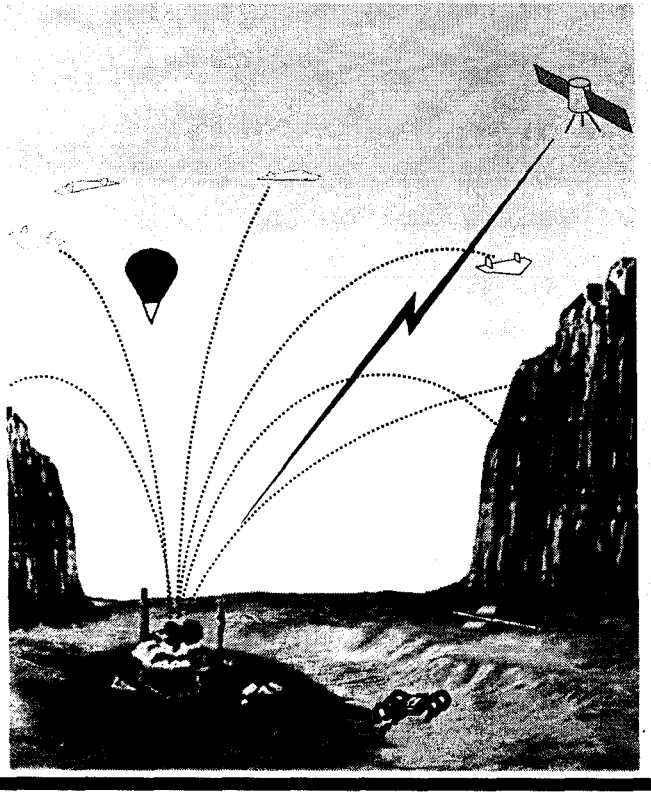
MARS MISSION: BIOMORPHIC CO-OPERATIVE Surface-Aerial-Microflyer SCOUT MISSION

ON-CALL MICROFLYERS SURVEY SELECTED SITES

- CLOSE-UP IMAGING/ DEPLOY PAYLOAD
- RANGE ~ 100 Km



- Lander contains: ~ 15Kg Surface Crawler(1or 2)
- ~ 15 Kg Microflyers (~ 5 -15)
  - Surface or Areal launch to selected sites (gorge, canyon) of microflyers
  - Precompute angle and aerodynamics for launch of microflyers to selected site
  - Simple solar navigation, demo bio-inspired
    - Hazard avoidance & terrain following in Valles Marineris equivalent
  - Range ~ 100 Km, multiple local relays (both surface and aerial) provide robust data return architecture
    - Legged Crawler speed: 1 m/s
    - Microflyer speed : ~ 100 m/s
  - High resolution close-up imaging of selected site
  - Distribution of Instruments/Experiments/tiny surface explorers to targeted sites for in-situ measurements/exploration.
  - Microflyers resupply provisions for crawlers to extend lifetime for surface exploration

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MARS MISSION: TIME STEPS IN CO-OPERATIVE Surface-Aerial-Biomorphic Microflyer IMPLEMENTATION

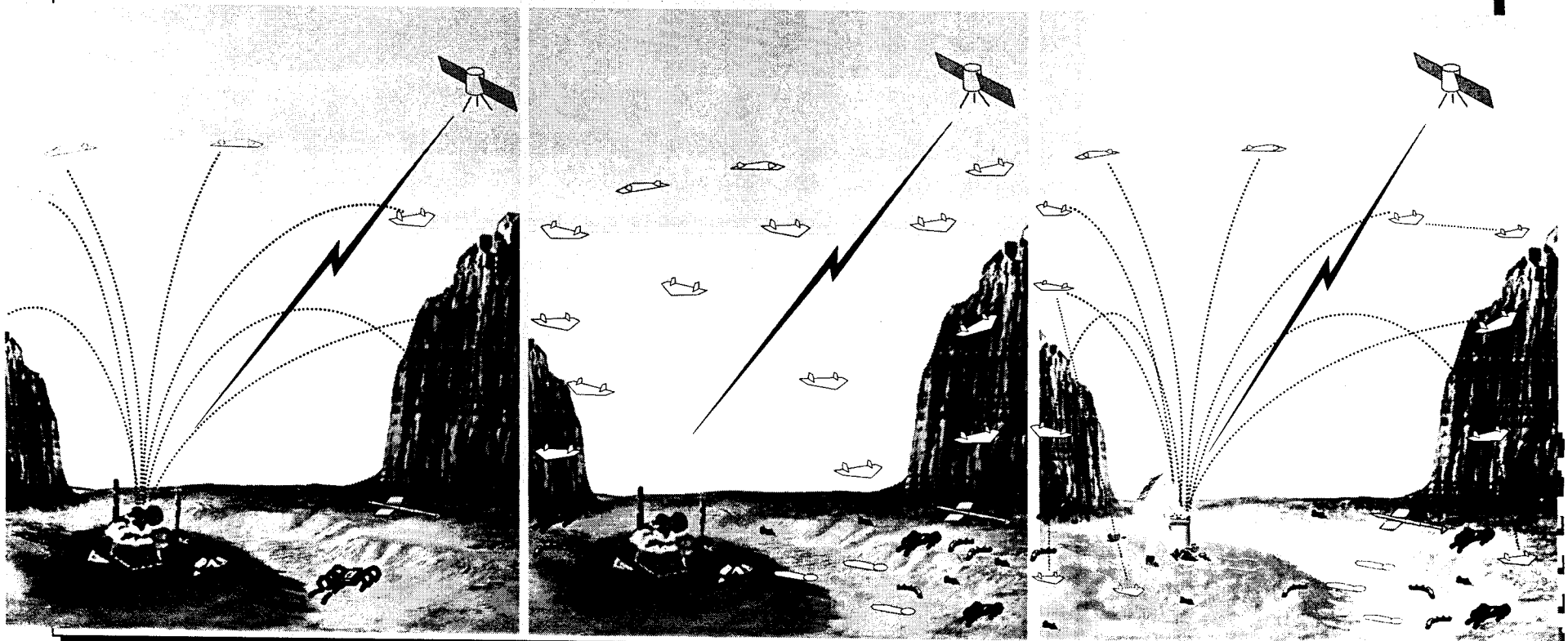
ON-CALL MICROFLYER

- CLOSE-UP IMAGING/ DEPLOY PAYLOAD
- RANGE ~ 100 Km

CO-OPERATIVE 3 MICROFLYERS OR MORE

- RANGE≥ 1000 Km
- DYNAMIC ROUTING OF DATA BY SELF ORGANIZATION

MICROFLYERS TO EXTEND ASTRONAUTS SENSING REACH TO HAZARDOUS/INACCESSIBLE AND DISTANT LOCALES



Ref: S. Thakoor, Journal of Space Mission Architecture, Issue 2, 2000, pp 49

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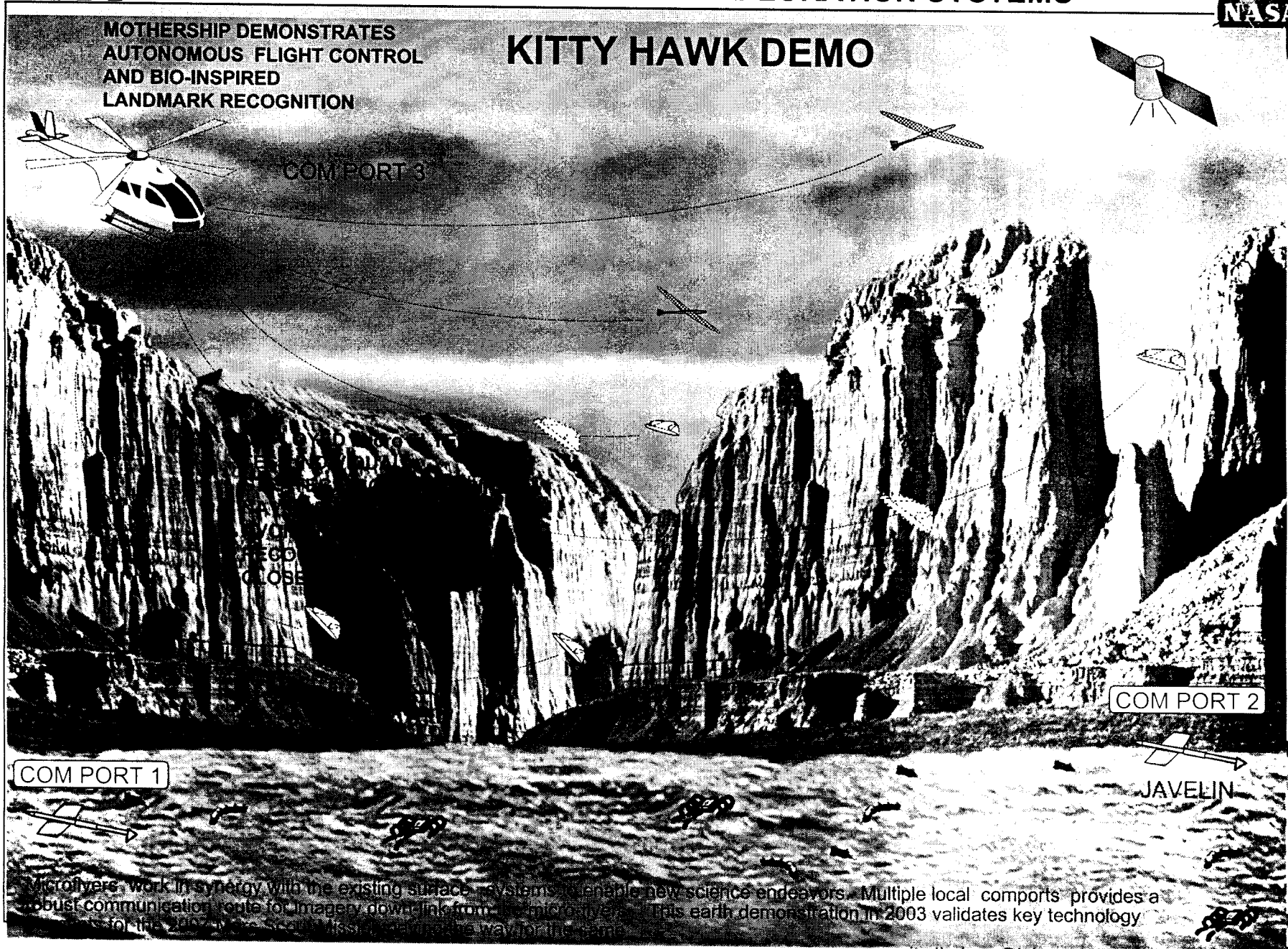
BIOINSPIRED ENGINEERING OF EXPLORATION SYSTEMS



Microflyers work in synergy with the existing surface systems to enable new science endeavors. Multiple local comports provides a robust communication route for imagery downlink from the microflyers. This earth demonstration in 2003 validates key technology for the 2007 [illegible] Mission paving the way for the same.

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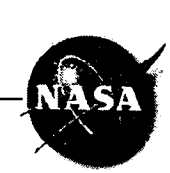

Applications (Dual Use NASA & DoD)

- Close-up Imaging, Site Selection
- Meteorological Events: storm watch
- Reconnaissance
- Biological Chemical Sensing
- Search and Rescue etc.
- Surveillance
- Jamming

- Distributed Aerial Measurements
  - Ephemeral Phenomena
  - Extended Duration using Soaring

- Delivery and lateral distribution of Agents (sensors, surface/subsurface crawlers, clean-up agents

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BIOMORPHIC EXPLORERS

- **PAYOFF:**
- **MULTIPLE USE NASA/DoD/NIH/NCI**
- **BIOMORPHIC EXPLORERS, IN COOPERATION WITH CURRENT EXPLORATION PLATFORMS CAN ENABLE**
  - **EXPLORATION OF CURRENTLY INACCESSIBLE AND/OR HAZARDOUS LOCATIONS**
  - **MUCH BROADER COVERAGE OF EXPLORATION SITES**
  - **LOW MASS, LOW POWER, HIGHLY ROBUST ADAPTIVE SELF HEALING SYSTEMS**
  - **EXPLORATION AT LOWER COST**
- **MINIATURIZED MICRO/NANO BIOMORPHIC EXPLORERS CAN BE USED FOR DETECTION/DIAGNOSIS/TREATMENT OF DISEASES AND AILMENTS OF HUMAN BODY NON-INVASIVELY AT LOW COST**

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